O3.COVID-19_1 – Implementation and adaption of tools for RoboSTEAM in COVID-19 times

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Version History

Version	Date	Comments
0.1	31/10/2020	Adaption HIL prototype for Hackaton
0.2	30/11/2020	First SUFFER version for education
0.3	31/12/2021	Second release of both prototypes
1.0	15/01/2021	SUFFER updates for C6
1.2	31/03/2021	Final adapted version of both tools
1.2.1	29/05/2021	Errata correction
1.2.2	29/05/2021	Errata correction

Table of Contents

1. O3.COVID-19_1

This document describes part of the work of the Output 3 – RoboSTEAM Environment [1], specifically one activity added because of COVID-19 pandemic situation. In RoboSTEAM project [2-9] schools should be able to continue with the piloting, but with the lockdown and the migration to an online version of part of education activity this something difficult. Given this situation and taking into account the results gathered by O2.COVID-19 the project partners decide to develop/adapt software tools to facilitate simulations in which it was possible to carry out robotics challenges. This activity is described as follow in the project management handbook:

> "*After the identification of these tools the project universities propose two possible tools to be applied SUFFER and HIL prototype. Both of them were adapted to be applied virtually and later the idea is to test them with the schools during the Hackathon and C6.*"

In this output report we described both prototypes, where they were necessary, and the adaptions carried out. In O2.COVID-19_2 we describe the testing of these implementations in educational context.

2. THE PROCESS

In March of 2019 COVID-19 [10-20] arisen and it implies an important change in all educational contexts and of course also an impact for this project. In several countries there was a general lockdown and classes should switch to online version. This implies changes both for the institutions (that requires new plans and tools), the teachers (that need to learn to use the tools and adapt their contents) and the students (that requires to use the new paradigm).

Given this situation, the RoboSTEAM project detected several necessities, but especially relevant for it is to provide the schools with platforms and tools to continue with the pilots and challenges. In this situation and, after identifying tools through the Systematic Review (O2.COVID1), we decide to carry out two tool adaptions a Hardware in the Loop prototype (HIL) and a simulator as a service (SUFFER).

The development began in October 2021 (M24) with HIL prototype which first release was at the end of this month in order it can be tested during the Hackathon carried out in IPB the 3rd of November. After it, feedback was provided, and changes addressed. At the same time during November SUFFER, a System defined initially as a honeypot to receive cybersecurity attacks, began to be adapted to provide a simulator environment in education. There is a stable release of both system at the end of December 2021, although SUFFER version was adapted in January 2021 in order to be tested in the C6 virtual exchange by the project partnership. In the next sections we described both tools and how they are applied in educational context with some photos.

3. Hardware in the Loop Prototype

Hardware-in-the-loop systems have been widely applied because of their advantages during the process of development. The main areas that have been developing and adopting HIL are aeronautical industries, automotive industry and power systems, among others. Another field in evidence is robotics. HIL can be used in mobile robots, which are constantly optimizing their performance.

The developed hardware-in-the-loop (HIL) tool provides a feature to test the hardware responsible for controlling all actions of the real robot but controlling the virtual robot instead through Serial (USB) communication. In other words, the simulator will provide the sensor data (encoders, light, etc.) to the embedded controller in the hardware, which will process the data and control the actions of the virtual robot.

The HIL tool provides the possibility for students to implement their scripts in the microcontroller that will control the real robot and perform tests on the simulated robot, reducing errors in design, algorithms, controls and logic. The HIL deals with the real limitations of the microcontroller used to control the robot. The memory requirements and the processing limitations of a microcontroller are stressed and return the real problems minimizing the gap between the simulation and the reality.

Before migrating the code to the robot and testing it in real environment, a sequence of three procedures is suggested to validate the control script. This proposal consists in performing tests available in the simulator, subjecting the developed control code by the student to different conditions. The HIL tool provides the possibility for students to implement their scripts in the microcontroller that will control the real robot and perform tests on the simulated robot, reducing errors in design, algorithms, controls and logic. The HIL deals with the real limitations of the microcontroller used to control the robot. The memory requirements and the processing limitations of a microcontroller are stressed and return the real problems minimizing the gap between the simulation and the reality. With a defined period, the control loop is updated by the microcontroller that receives the data, processes it and sends the control data to the simulator.

Two main examples were developed using the mobile robotics area: The Robot@Factory Lite and the micromouse competitions.

The first one results from the competition that was stablished on the Portuguese Robotics Open on the last years. With this methodology, students can develop skills from the most basic ones, such as line following, to the complex ones such as path planning and scheduling. Figure1 shows the developed real robot and the CAD simulated one.

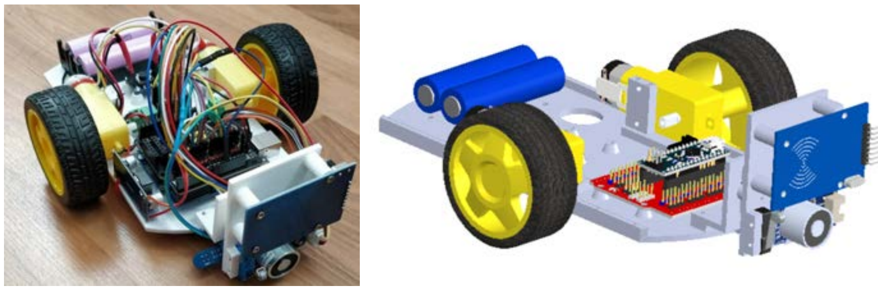

Figure 1. – Real robot and CAD simulated one.

Students are encouraged to develop the hardware, according to the following schematic, where the robot is powered by two Lithium 18650 batteries and a step-down converter, an Arduino Uno, two motor and drivers and a magnet as actuators and as sensors there is installed an RFID reader, a button and an IR line sensor (Figure 2).

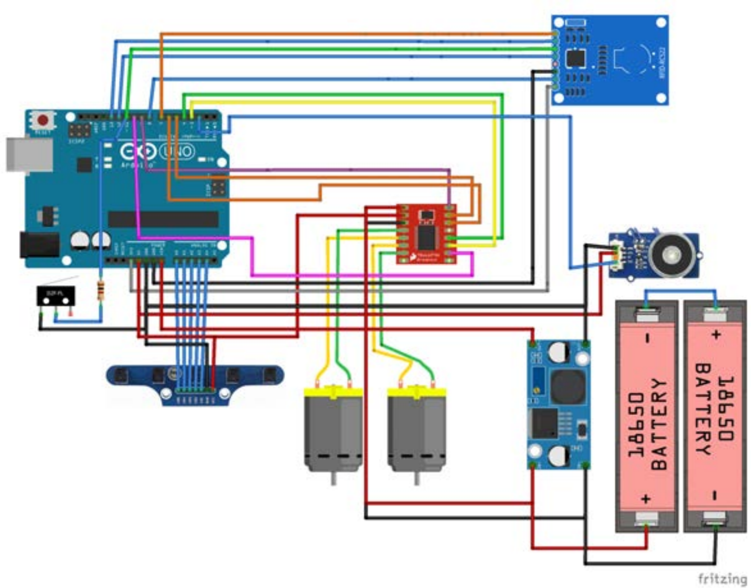

Figure 2. – Robot description

The Hardware-in-the-loop system will use a simulation of the environment, but the modelled robot will be controller by a real Arduino connected by USB. Figure 3 shows the main architecture of the HIL and the data communication between both components. The simulator SimTwo was used to include the HIL capability.

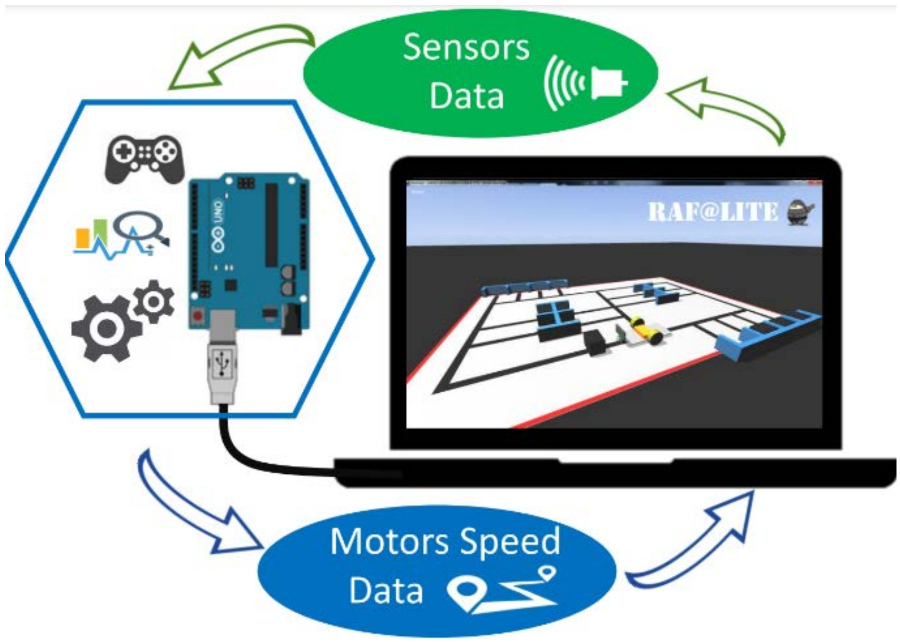

Figure 3. –Architecture of the HIL

With this methodology, students can develop and test the programs using just an Arduino Uno board and without the complex setup.

The second developed example using the HIL approach is the well-known Micromouse competition. For this mobile robot, a WeMos ESP8266 microcontroller that can be programmed using the Arduino IDE, was used. For the simulation purpose, the Unity was successfully tested where the model of the robot was embedded. Next figure allows to check, at left the real developed robot whereas at right the modelled one.

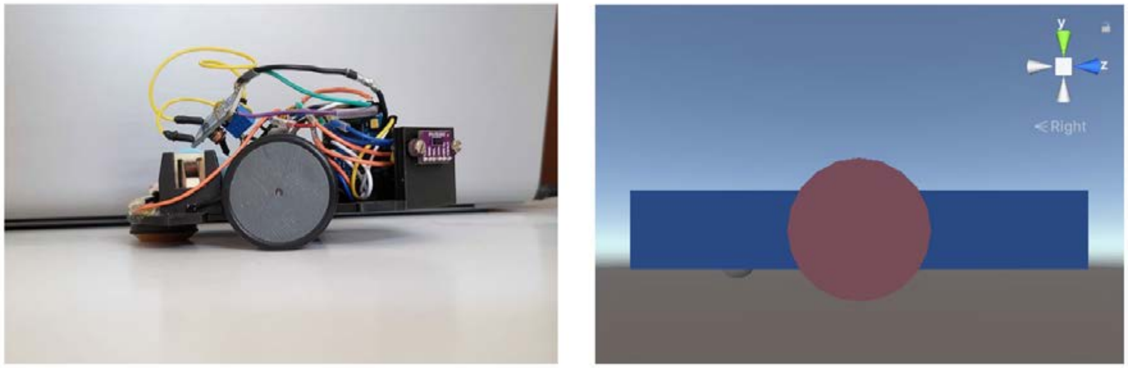

Figure 4. – Mobile robot implementation an simulation

The main architecture of the system is presented in Figure 5. From the simulator side, the robot model and its components (such as motors, sensors and encoders) are introduced. From the point of view of the microcontroller, the robot control, the path planning and the data analysis are stressed at the microcontroller level.

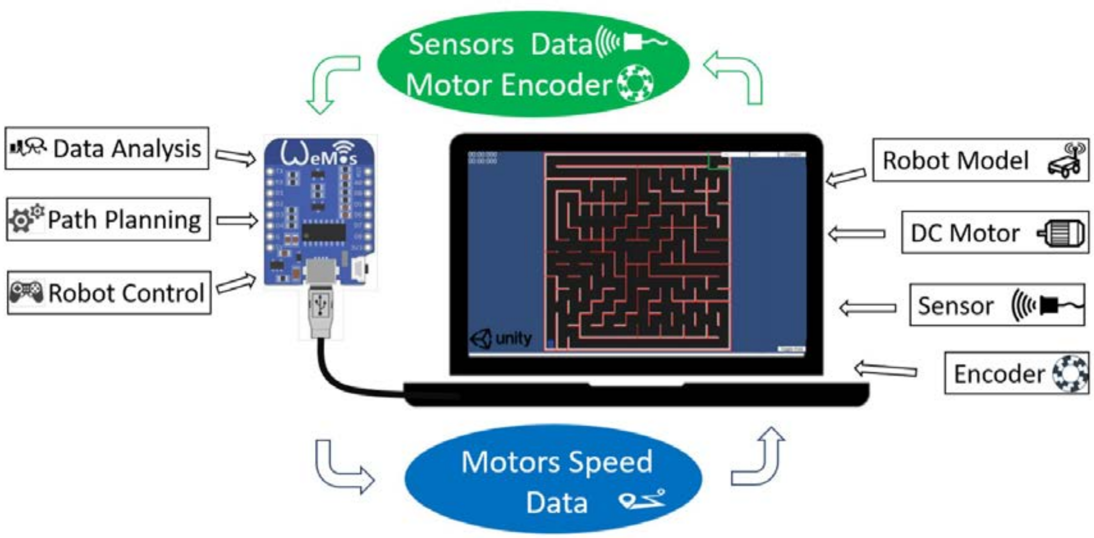

Figure 5. – Architecture of the mobile robot

As conclusion, two Hardware-in-the-loop scenarios were developed. These scenarios can be used to teach students, to stress different methodologies without access to hardware. The actual pandemic situation also pushes the proposed system to be used by students with problems on accessing or developing a real robot. The define prototypes were used during the Hackathon carried out in Portugal.

4. SUFFER

The SimUlation Framework for Education in Robotics (SUFFER) defines the platform designed and developed in the group for performing online robotics laboratories.

Initially it is developed as a honeypot to test software vulnerabilities, but later evolves in a cloud platform where the teachers can simulate robots and even to provide access to a real robotic platform.

Initial architecture using the simulator as a container with a middleware layer based on ROS (Robotics Operating System), a simulation of the robot as a platform, the Gazebo simulation as application and a dataset with real sensor information. This first idea was generalized to be used with any other middleware, data and application, which becomes suffer in a very flexible cloud platform to define remote labs that can be used from a Container as a Service (CaaS) perspective, from a Platform as a service (PaaS) perspective or from a Service as a Service (SaaS) perspective. The type of use will depend on the teacher requirements for implementing the course.

The main advantages of SUFFER comparing it with the usual Virtual Remote Desktop Labs are:

- SUFFER is a generic and customizable remote lab to define different virtual desktops similar to those physically available in the lab. It allows access to remote computing environments under those limitations of software and hardware defined by the teacher.

- It is very flexible to integrate different kind of technologies. It is very scalable to support an important number of students, in fact, now experiments are being carried out with more than 200 machines working at the same time.
- It is possible monitoring what students are doing in different ways. For instance, we can check the performance of the active machines, used in SUFFER, but also the students' interactions with the machines (Figure 7 shows samples of this) and we can also apply the own monitoring tools included by the installed platforms or apps.
- It supports teachers' feedback on real-time. It is possible to access to any SUFFER machine and help the students for solving the problems during the live sessions.

Regarding the architecture SUFFER lays out the possibility of deploying specific labs with predefined characteristics attending teachers' needs. SUFFER can offer a complete infrastructure simulating a real PC (infrastructure as a service IaaS) and some of their derivatives Container as a Service, Platform as a Service and Software as a Service.

The features of an IaaS approach would allow offering practical labs for any kind of technical courses. Thus, it is possible to teach not only programming principles but also Operating Systems or Network courses. However, it is necessary to narrow down and monitor the cores elements in the machine, both regarding maintenance and cibersecurity. For this reason, the more general perspective of the project has been postponed for future iterations. Figure 6 shows graphically the elements included in SUFFER in the context of robotic labs.

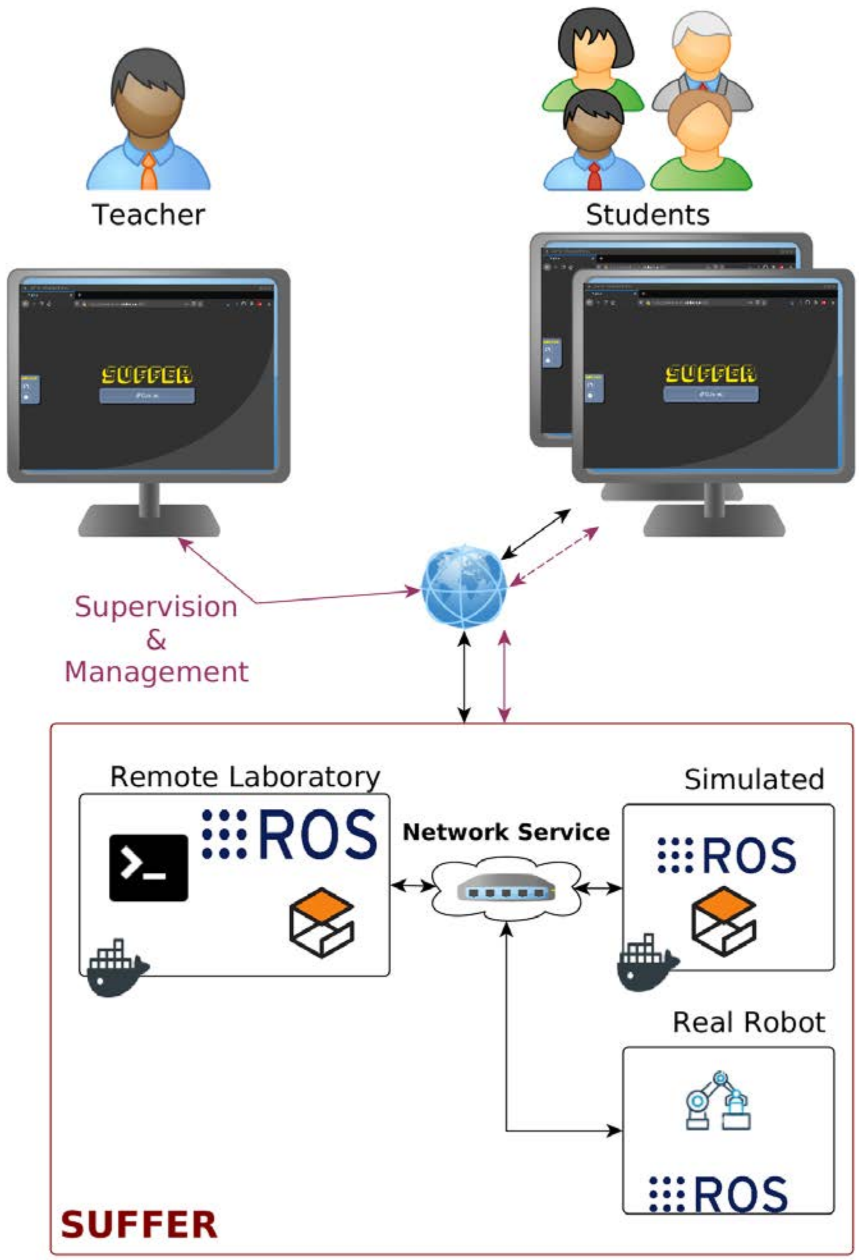

Figure 6. – SUFFER architecture in a Robotics Lab

As the main objective of SUFFER is to adopt an approach oriented towards services on cloud to provide the technological resources needed by the teacher and, thereby, by the student too, it can be used as a course session generator. In this way, the teacher can focus completely on the specific knowledge to be transmitted and the student can focus on getting it. It can be used in three different ways:

- For the teacher that wants himself to deploy the software needed for his class, a pool of containers will be offered with just an operating system installed. In these containers, the teacher will have access to installing and removing everything needed. This way, not only the code of applications should be loaded, but also all technical requirements for coding, compiling and managing the applications to be used. The approach used to solve this scenario is mainly based on containers, and it is therefore associated to a CaaS scenario.
- For the teacher that decides to use an approach based on predefined containers for his classes, an advanced environment will be provided with software already installed. This option prevents the teacher from the management of the middleware and minimizes configuration problems. This way, the teacher relies on the technologies supplied by the provider and deploys the applications and the corresponding data sets together with the platform. This case is considered as PaaS solution.
- The third option considered in SUFFER framework is the SaaS solution. In this case, the whole infrastructure needed for the lab is offered to the teacher, that is, students will be working with a closed platform where the addition of new content should be minimal. Although modifying the platform by adding new material can be blocked, we consider that offering the possibility to include new elements that could improve the class is the right choice for a successful practical session.

Another important feature of SUFFER is monitorization. Beyond the technological infrastructure of the lab, it is necessary to offer monitoring tools in order to reduce the inactivity time of the three main actors, that is, the tool, the teacher and the student. The tool should minimize the no productivity periods of time or the possible system crashes. The amount of money employed in hiring an infrastructure on the cloud cannot be lost because of unavailability of the service. The goal is to provide distributed resources capable of being used in an optimal use.

Teachers can perform monitoring actions for following the progress and evaluation of their classes. This would also allow to perform an evaluation of students' performance at the end of each session. For instance, figure 7 shows the state of four different sessions of students: two of them have not entered yet, and the other two are already working on their assignment. When used together with a videoconference tool, SUFFER allows the teacher to interact directly with the student desktop in order to solve or fix a problem.

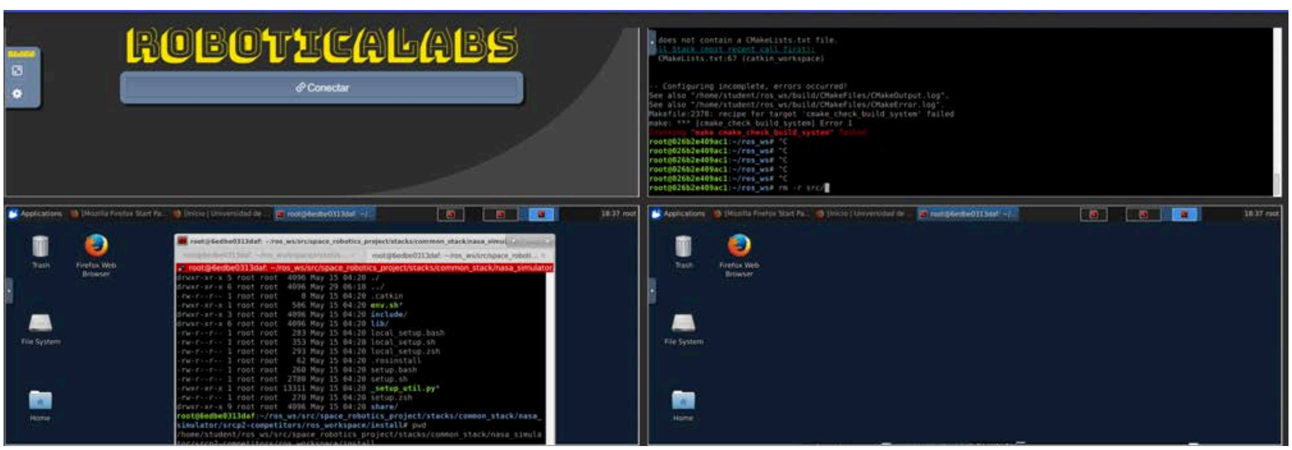

Figure 7. – Monitoring System v1. Based on simple HTML

These three lines of supervision allow the improvement of the resources of the cloud system and the services offered to every teacher. At the same time, they facilitate optimizing the mechanisms used to properly provision the resources offered at any time. This supervision allows also the observation of possible limitations of the system and the proposal of mechanisms to solve them.

In the current state of the research, besides the direct supervision of the students by the teacher, SUFFER offers a monitoring system and also a mechanism to launch events associated to files and applications. Their source are mainly the log files provided by the applications and the user interaction with the terminal. This information turns out to be of great importance for lab activities related to computer science in particular. This monitoring can take place one time or through historic data. In both cases, the analysis of this data is of great value to analyse how students solve their practical assignments.

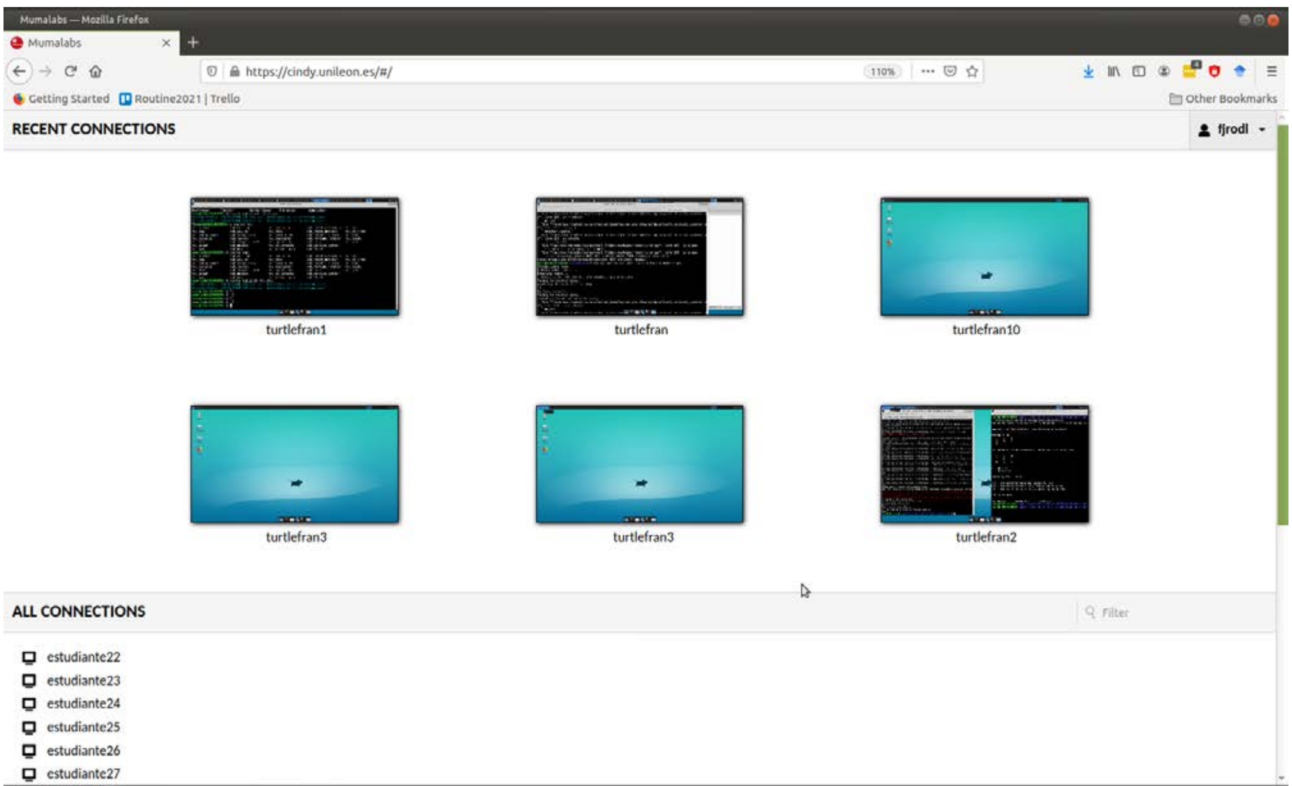

Figure 8. – Monitoring system v2. Base don Guacamole

The case of SUFFER development for RoboSTEAM implies maintaining the support for Robotics simulation but also collaborative working among the students of a pilot group. The teachers and experts can monitor what the users have done by using Guacamole system.

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